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A geodesign framework procedure for developing flood resilient city

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ABSTRACT

Extreme rainfall and sea level rise under climate change may increase the risk of flooding and thus threaten people's lives and property. Accordingly, the concept of flood resilient urban design has been proposed, in which methods for managing the climate impacts while maintaining the cities' functions have been investigated. This study provided insights into the urban lagoon transformation of Tainan City introduced by the International Landscape Design Competition for Tainan Axis Transformation. The focus was put on flood resilient geodesign based on a nine-step framework through data analysis (GIS-based), design optimization (rule-based), and decision support (web-based) process that helps to determine whether the lagoon design fully incorporated the influential factors of flooding in its urban transformation. This study utilized rule-based modeling to build an interactive three-dimensional (3D) urban design platform, combine potential flood risk information, and propose design approach to support decision making for urban resilience. A workshop was organized to compile the public's opinion utilizing the platform for design, communication, and interaction. Lessons from the urban lagoon transformation of Tainan City indicated the need for flood resilient geodesign for urban redevelopment, and the inclusion of both government and public opinion to advance urban design in a changing climate.

1. Introduction

Resilience and urban risk management presents the need for planning and designing resilient cities (Serre, Barroca, & Laganier, 2012). Rapid urbanization and climate change have increased both the flood probability and the severity of flooding (Serre, Barroca, Balsells, & Becue, 2018). As urban flood resilience under climate change is concerned, this study provided insights into the concept of urban lagoon transformation introduced by the International Landscape Design Competition for Tainan Axis Transformation hosted by the Tainan City Government in 2015. The focus of the study was put on the need for geodesign approach to advance urban planning and design towards flood resilient city in a changing climate. The scope is to narrow down resilience from an all-encompassing concept to applied ways in terms of disaster (flood) related resilience (Fekete & Fiedrich, 2018).

The international design competition primarily entailed enhancing the quality of urban life through developing an underground open lagoon space, building an accessible space of urban waterfront through the use of rainwater, and adding tropical plants and pedestrian trails. The goals of the competition were to bring citizens closer to the city's canal and integrate the city's blue belt and green belt projects. The study site of the design competition is located in the West Central District, the city's most densely populated area (Fig. 1). The winner of the competition was the team consisted of the Urbanists Collaborative in Taiwan and the Netherlands-based architecture and urban design practice MVRDV. Their concept on the urban lagoon transformation aims to reconnect the city with nature and its waterfront by creating a lagoon on the site of the former China-Town Mall and a green corridor with public interventions along Haian Road in terms of urban lagoon transformation.

Faced with this challenge, this study employed a geodesign method to inspect whether the Tainan City Government fully incorporated influential climate factors in its urban development. It is noted that inadequate governance processes and land uses may exacerbate urban vulnerability to flooding. This calls for a new agenda for policy strategies for creating flood resilient cities. In Methods section we introduce an innovative nine-step geodesign framework procedure supported by three-dimensional (3D) modeling based on Geographic Information System (GIS); rule-based modeling was utilized to build an interactive 3D platform that addresses urban design in geographic space while receiving feedback for decision making. In Results and discussions section, we argue that this geodesign approach enables stakeholders to understand and deal with the complex data analysis (GIS-based), design optimization (rule-based), and decision support (web-based) in adapting to climate impacts. That is, we used combined potential disaster information to simulate the scale of flood risk, proposed planning and blueprints for resilient cities, and organized a workshop to listen to the public's opinion.

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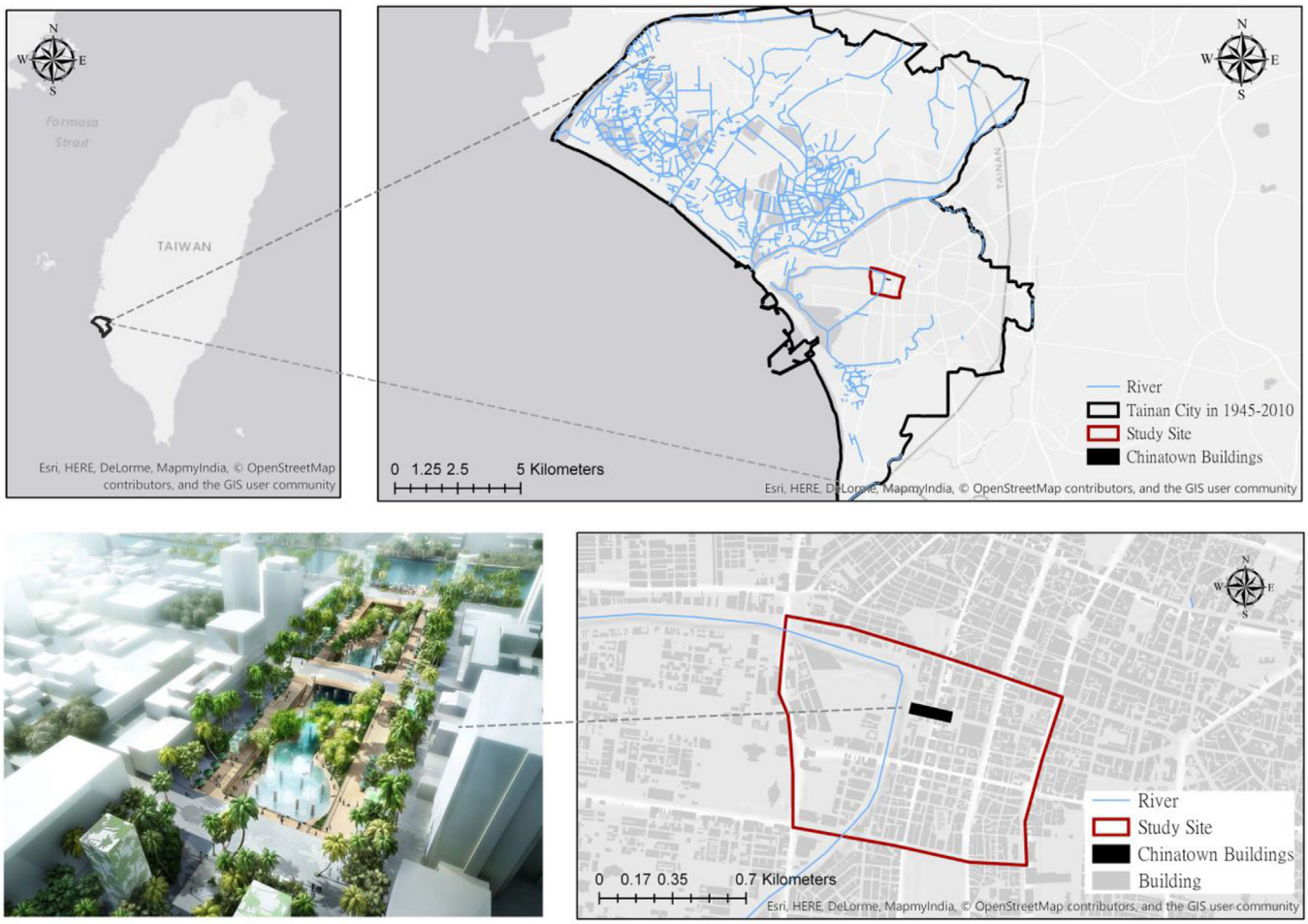
Formosa Strait
TAIWAN
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0 1.25 2.5 5 Kilometers
River
Tainan City in 1945-2010
Study Site
Chinatown Buildings
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River
Study Site
Chinatown Buildings
Building
0 0.17 0.35 0.7 Kilometers
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Fig. 1. Study site and simulation performed using the transformation designs introduced by MVRDV (2015).

The study site is located in the low-lying area of Tainan City, which is a special municipality with urban density about 4500/km2 and the oldest city of Taiwan, facing the Formosan Strait (Taiwan Strait) in the west and south. In addition, the site is close to a newly emerged coastal plain with an average elevation of 2–3 m above sea level (Hsiung & Saito, 2017). However, it gradually became tidal land and currently serves as the location of Tainan City Hall. Because Tainan's southwest coastal regions are lowlands, they are prone to flooding caused by elevated sea levels and extreme rainfall. These regions will inevitably encounter severe flood challenges in the future (Chang & Huang, 2015). Because flooding is the most immediate threat to this area, devising adaptation plans related to resilient city and sustainable development is particularly crucial.

2. Methods

2.1. Geodesign

Geodesign using GIS and other visualization tools enabled the stakeholders to focus on urban development patterns, and environmental characteristics of the city (Lee & Gamez, 2017). It provides a systematic way to build master plans, develop climate change and resilience strategy (Borges & Ballal, 2017). Based on the current challenges encountered in the study site and the demand for its geodesign, this study proposed that urban design needs to take into account the future environment and landscape changes if the city is to undergo sustainable development. geodesign emphasizes the use of geography techniques to facilitate developing landscape and urban planning-related designs. The concept of geodesign has emerged in recent years and primarily integrates the fields of geography and design (Trubka, Glackin, Lade, & Pettit, 2016; Wilson, 2015). Previously two separate domains, geography and design have been merged together following frequent recent occurrences of natural disaster induced by climate extremes and the greenhouse effect. Because the development of sustainable and resilient cities demands that a number of complex issues be considered (Kulawiak & Lubniewski, 2014; Musa, Popescu, & Mynett, 2016), geodesign has been regarded a crucial theory for realizing such development. Measures implemented in the past to block floods have involved the construction of various flood control facilities. However, as extreme climate events become more frequent, the traditional method of building walls to prevent floods is no longer sufficient for mitigating the threat posed (Liao, 2012). Identifying how a city's functions and operations can be restored within the shortest possible time has become a topic that all governments must address. Resilient city plans emphasize the collection, analysis, and assessment of data on a city's current overall state and the formulation of plans and designs on the basis of the assessment results. These efforts increase a city's ability to adapt to disasters and enhance its overall resilience (Xu & Coors, 2012; Chiang & Huang, 2016).

Geodesign is such a hot topic these days that ESRI, the leading worldwide company in the GIS industry has been organizing annual Geodesign Summit meetings since 2012 (Haddad, 2015). Geodesign is primarily discussed in sustainable urban development and resilient city planning–related discussions (Wong, Jusuf, & Tan, 2011). The rise in popularity of geodesign is a result of the considerable impact and threat of extreme climate-led natural disasters on human lives and property; the necessity for long-term planning and designing of urban and landscape projects; and the need for people to adapt to and mitigate the

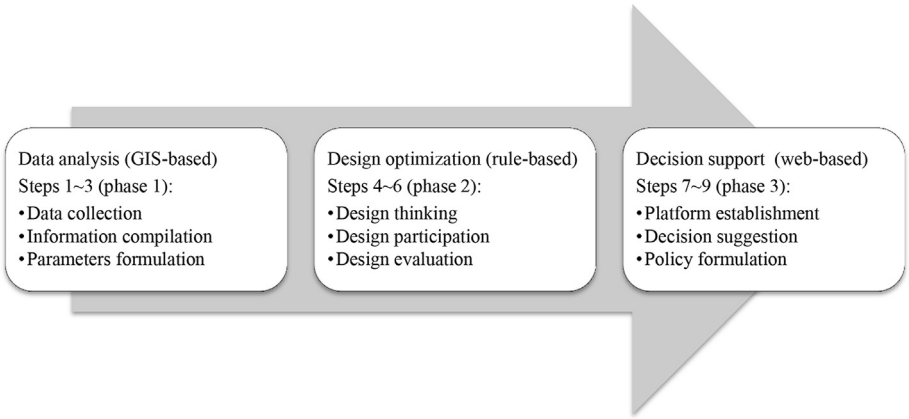


Fig. 2. The nine-step geodesign framework procedure of the study.

Table 1
The nine-step geodesign framework procedure and key messages derived from ScienceDirect references that address keyword *geodesign*.

References	Data analysis	→		Design optimization	→		Decision support		
	Data collection	Information compilation	Parameters formulation	Design thinking	Design participation	Design evaluation	Platform establishment	Decision suggestion	Policy formulation
Huang & Zhou, 2016	1	1	0	1	1	1	1	1	0
Wilson, 2015	0	1	0	1	1	1	0	1	0
Nyerges et al., 2016	1	1	0	1	1	1	1	1	1
Slotterback et al., 2016	0	0	0	1	1	0	1	1	0
Dangermond, 2010	1	1	0	1	1	1	1	1	1
Perkl, 2016	1	1	1	1	1	1	1	1	0
Wissen Hayek, von Wirth, Neuenschwander, & Grêt-Regamey, 2016	1	1	1	1	1	0	1	1	0
Eikelboom, Janssen, & Stewart, 2015	1	1	1	1	1	1	0	1	0
Yang, Quan, Castro-Lacouture, Rudolph, & Stuart, 2014	0	1	1	1	0	1	1	1	0
Trubka et al., 2016	0	1	1	1	1	1	1	1	1
Importance value	**6**	**9**	**5**	**10**	**9**	**8**	**8**	**10**	**3**

Note: 1 and 0 indicate related and unrelated, respectively.

effects of future natural disasters (Abid, Schilling, Scheffran, & Zulfiqar, 2016; Carlson & McCormick, 2015; Lei, Zhang, Chen, & Zhang, 2016; Muis, Güneralp, Jongman, Aerts, & Ward, 2015).

2.2. 3D modeling

ArcGIS Pro 2.0, Esri's next-generation desktop GIS, that brings more of highly requested workflows to the table and features new innovations not available in any other desktop GIS (Kachelriess, 2017) is effective at displaying, automating and exploring geodatabase datasets through geoprocessing for the study site. Information is transformed into images and saved as different layers for an overall map. To build a collaborative platform to inform flood resilient urban design, two-dimensional (2D) visual research results are required for integration into the platform. Moreover, the research content of each image is saved as an attribute table, enabling researchers to keep the data updated. Through geomapping tools, the inserted data can be visualized easily and analyzed spatially.

For 3D modeling, ESRI CityEngine 2017.0 was used to introduce the concept of scenarios, with which multiple design alternatives within a scene can be created. Comparing and editing scenarios in side-by-side window views can fulfill the requirements of 3D-visualized geodatabase and link it with the design process, workflow, and related tools of geodesign in an efficient manner (Kim & Wilson, 2015; Miller, 2017; Neuenschwander, Hayek, & Grêt-Regamey, 2014). It integrates the geographical environment with our researched, developing condition, thereby procedurally transforming 2D geo-based data into 3D evidence-based city models of the living environment. On the basis of procedural modeling, we can apply and examine the proposed adaptation strategies. Different adaptation strategies can be simulated through CityEngine's rule-based modeling and layering of graphics with attributes, thereby enabling tool operators to adjust proposed scenarios with a high degree of flexibility. The tool's systematic control and visual intuition encourage decision makers and others to collaboratively discuss and assess regional development choices effectively. Easy editing tools allow for quick sketching and texturing of 3D models during the discussion. In addition, CityEngine scenes can be published directly on the web for sharing project models, as well as analyzing the results or design proposals with decision makers and the public. The integration of the component of visualization creates a framework for regional intelligence towards sustainable development within the fusion of geodesign (Vaz, 2016).

2.3. Study framework

The geodesign framework utilizes information technology to facilitate collaborations between geographers, design experts, and the public, and performs dynamic and repeated analyses and assessments to

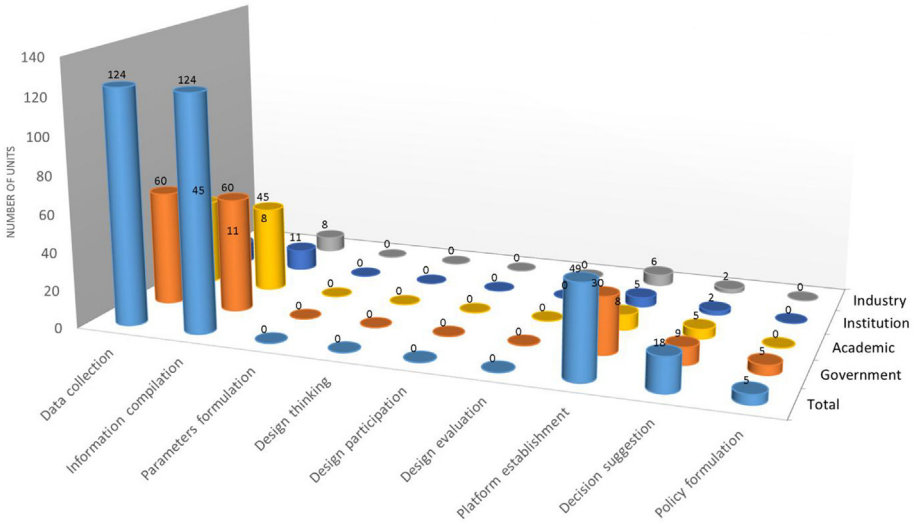


Fig. 3. GIS software usage situation in Taiwan; survey participants comprised local GIS software agents and dealers. The results revealed minimal use of GIS software and the gap that geodesign framework has not been used to tightly couple the creation of design proposals with impact simulations informed by geographic.

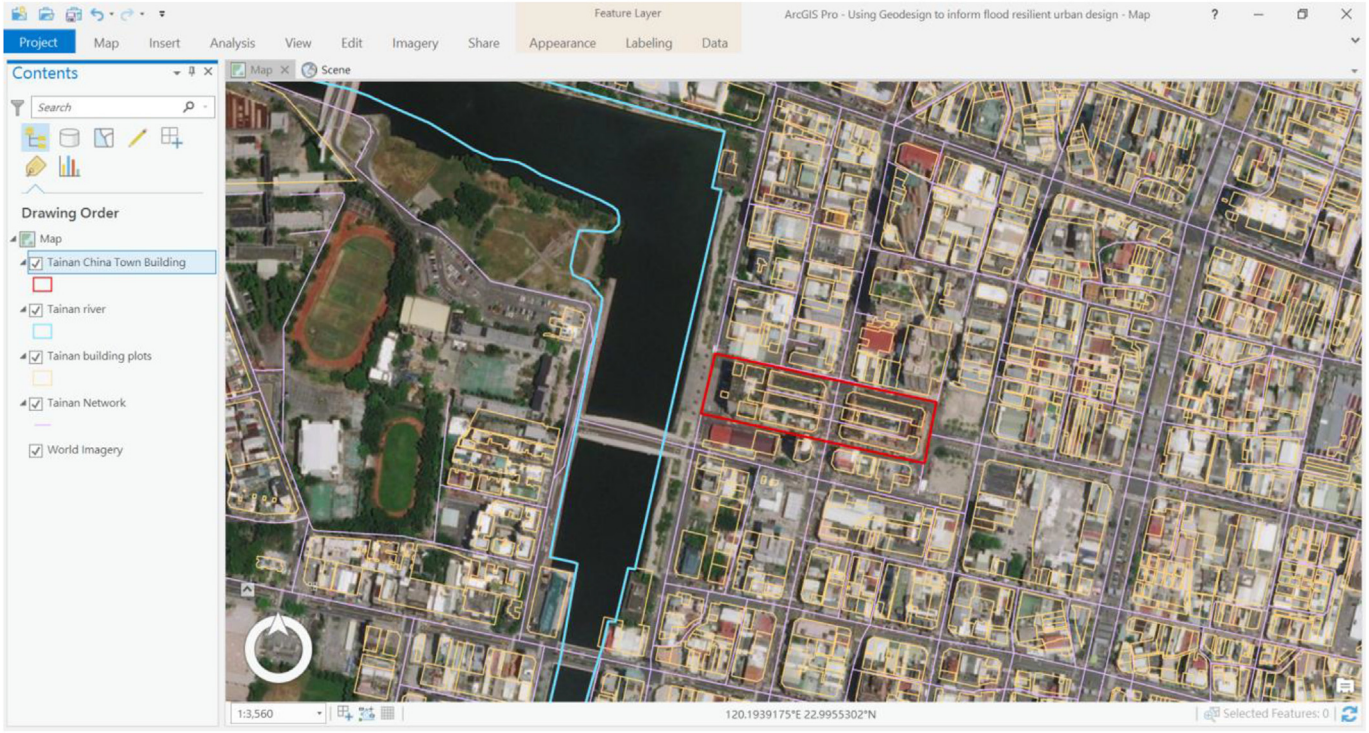


Fig. 4. Using the GIS map overlay function to integrate basic maps showing a city's current state.

locate and solve the identified problems in terms of solution-based design process (Perkl, 2016). That is, geodesign employs local geographical data and uses GIS as its design aid, making it a software tool as well as a specific process in which designs and analyses can be incorporated. In recent years, increasing numbers of researchers have begun to use GIS tools and technologies as a support to urban planning and design decisions (Acutis et al., 2014; Cerreta, Inglese, & Manzi, 2016) and as tools for urban development assessment. While GIS analysis results serve as the basis of urban planning, with spatial analysis tools employed to determine the scope of a region affected by an extreme climate, geodesign adopts spatial analysis techniques to facilitate the design process (Steinitz, 2012). It is noted that geodesign underscores iterative design method that uses stakeholder input, geospatial modeling, impact simulations, and real-time feedback to facilitate holistic designs and smart decisions (McElvaney, 2013). As such, this study compiled information obtained from the related literature that offers a revealing glimpse into the promise of geodesign and derived the following geodesign framework procedure that consists of three phases (data analysis, design optimization, and decision support) throughout nine geodesign steps (Fig. 2 and Table 1).

Data analysis (GIS-based) (phase 1) focuses on collecting background geospatial data and information on relevant geographic information technologies to enable effectively simulating and establishing models of the natural environment suitable for living; the steps 1–3 are introduced as follows:

1. Data collection: Collect background information on the study area and transfer the spatial data of the study areas to the geographic

Table 2
The influential factors of flooding were defined, graded, and weighted. The field "factor": Tainan is located on lowland plains prone to flooding; hence, the factors most likely to cause flooding were identified. The factors that easily caused flooding in Tainan; the field "domain of effect": Grid data of the maps were divided into four grades using the natural classification method. "Flood risks" in proposed weight of effect pertained to data obtained by the Central Emergency Operation Center through analyses and were thus fairly accurate. Flood risk was assigned a weight of 50%, and nearby canal and elevation, both of which were considered crucial influential factors of flooding, were each assigned a weight of 25%.

Factor	Domain of effect	Descriptive level	Define Level (1–4)	Proposed weight of effect (%)
Near river distance (m)	0–100	Very Hight	4	25%
	100–200	Hight	3	
	200–300	Moderate	2	
	300–400	Low	1	
Elevation (m)	0–4	Very Hight	4	25%
	4–8	Hight	3	
	8–12	Moderate	2	
	12–24	Low	1	
Flood Risk (m)	> 3	Very Hight	4	50%
	2–3	Hight	3	
	1–2	Moderate	2	
	0.5–1	Low	1	
SUM				100%

information database.
2. Information compilation: Assess the influential environment factors. The effects of these factors on the environment can be estimated using historical data.
3. Parameters formulation: Develop improvement methods and determine design parameters according to the influential environment factors.

Design optimization (rule-based) (phase 2) underlines geospatial analysis tools that can be adopted to analyze related problems and obtain planning and design results based on geographic information science, thereby meeting professional needs; the steps 4–6 are introduced as follows:

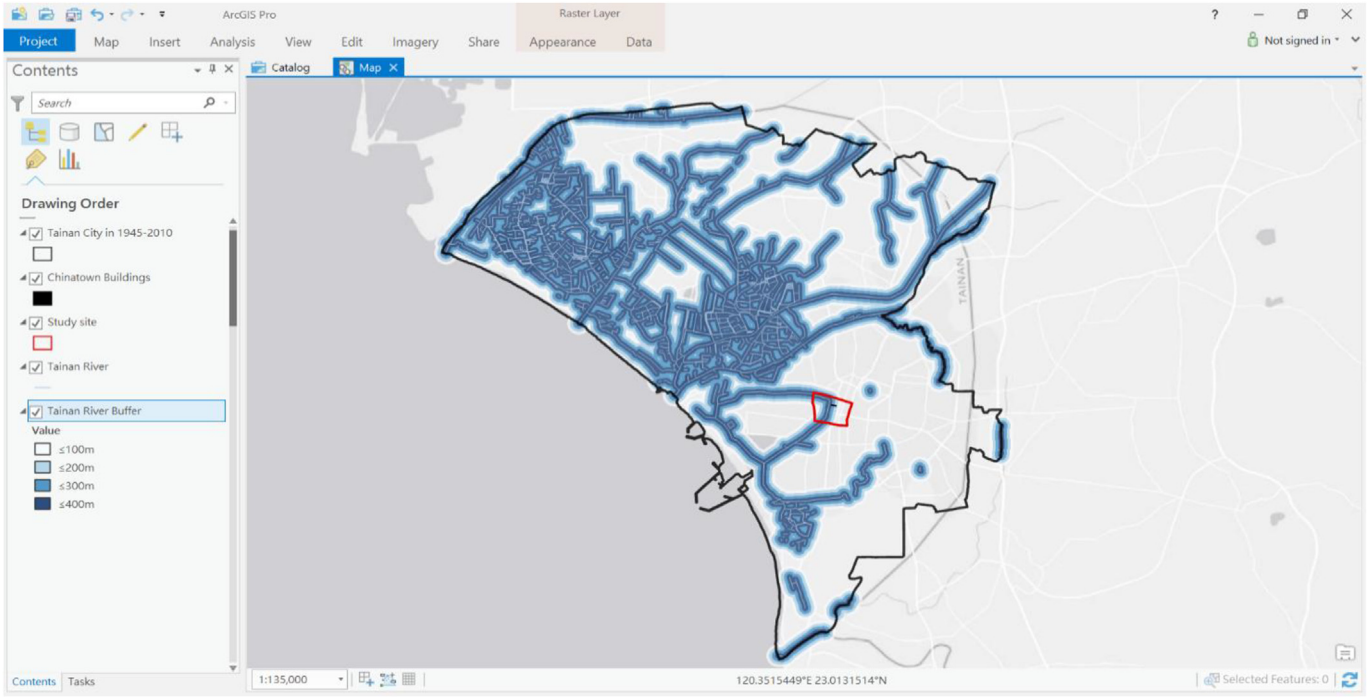
4. Design thinking: Incorporate the design parameters into the plans and designs.
5. Design participation: In this framework, the public, experts, decision-makers, and related stakeholders can engage in discussions and participate in the designing process.
6. Design evaluation: The public, experts, decision-makers, and related stakeholders can assess the designs.

Decision support (web-based) (phase 3) focuses on examining the data analysis and design planning results that enables identifying the strengths of various effects, formulating solutions to problems, and developing design parameters to effectively support decision execution; the steps 7–9 are introduced as follows:

7. Platform establishment: Build a geodesign collaboration platform to publicize planning results and enable the public, experts, decision-makers, and related stakeholders to offer suggestions and participate in the design process;
8. Decision suggestion: Formulate decision suggestions according to the planning results obtained from the geodesign process.
9. Policy formulation: Introduce policies according to the planning results obtained from the geodesign process.

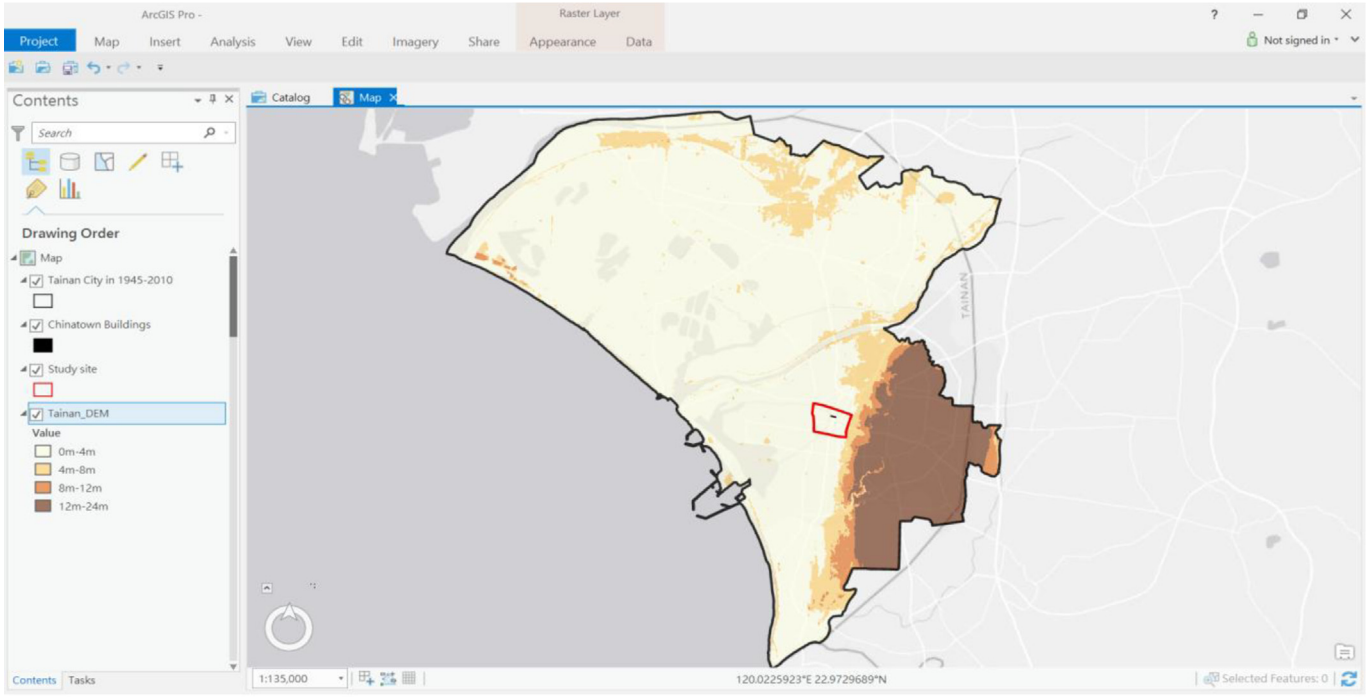
2.4. GIS application

This study addressed the usage of geodesign based on GIS application that allowed participants mainly comprised local GIS software



(a)

Fig. 5. Calculation of influential factors of flooding: (a) Calculate the grade indicating the distance to the adjacent canal; (b) obtain the 20 m × 20 m DEM grid data openly provided by the government; (c) overlay satellite images and flooding potential diagrams of regions with daily cumulative rainfall of 450 mm; (d) divide the grid data compiled in (a), (b), and (c) into four grades; and (e) illustrate the flood potential map of the study site using red channel for map control of CityEngine that should vary between 10 (0% red) and 100 (100% red) meters. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

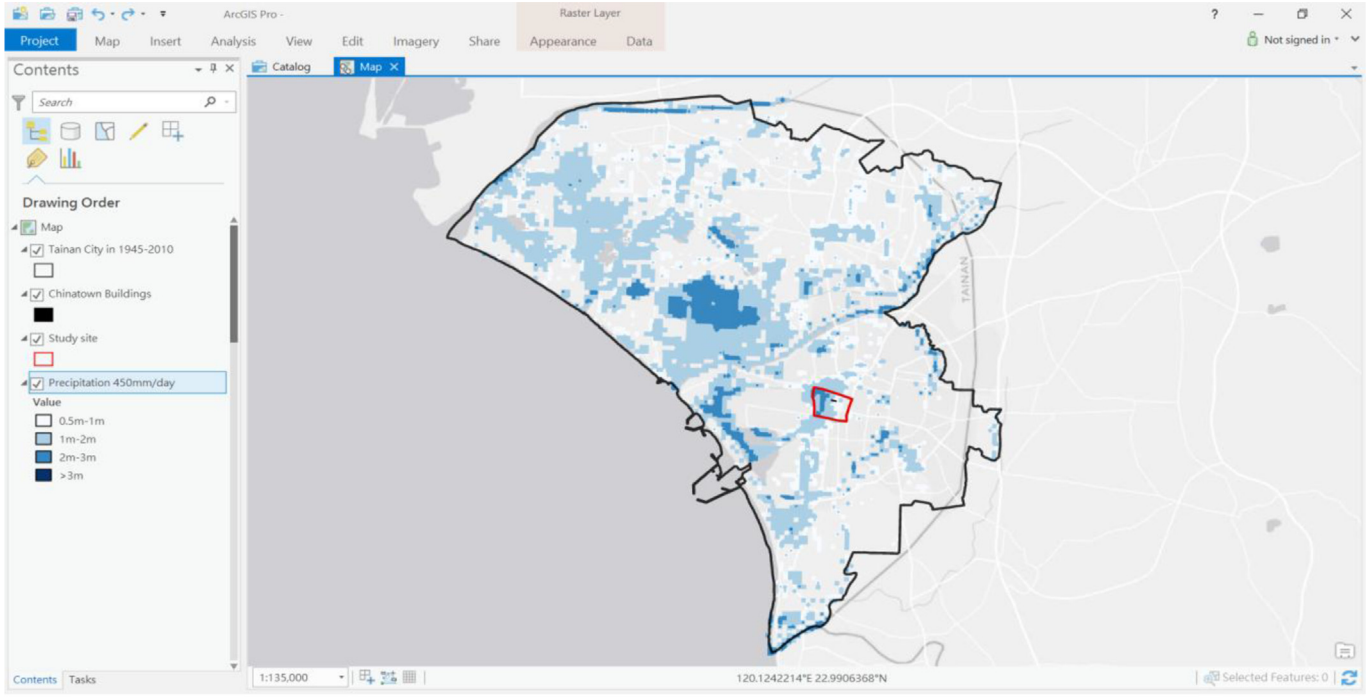


(b)

Fig. 5. (*continued*)

agents and dealers to explore the user demographics of various GIS programs. In addition, this study investigated the types of GIS software purchased by urban planning, design, and development-related departments to determine whether they implemented the tasks using GIS software in the context of geodesign. The software available was divided into four categories: GIS desktop software, analysis module software, 3D city modeling software, and server software.

The government and academic units were observed to be the primary users of geographic information in Taiwan (Fig. 3). Statistics have demonstrated that both the government and academic units frequently use a GIS to make assessments, employ GIS software to collect and control information, and utilize GIS server software to build platforms in the context of geodesign. In this study, the primary objective of such use is to build an information sharing and distribution platform to benefit the public, who will be able to search for and download various information, particularly regarding disasters as well as basic geographic maps. The collected data revealed that GIS-based techniques have matured in Taiwan; the compilation of basic data, the government's



(c)

Fig. 5. (*continued*)

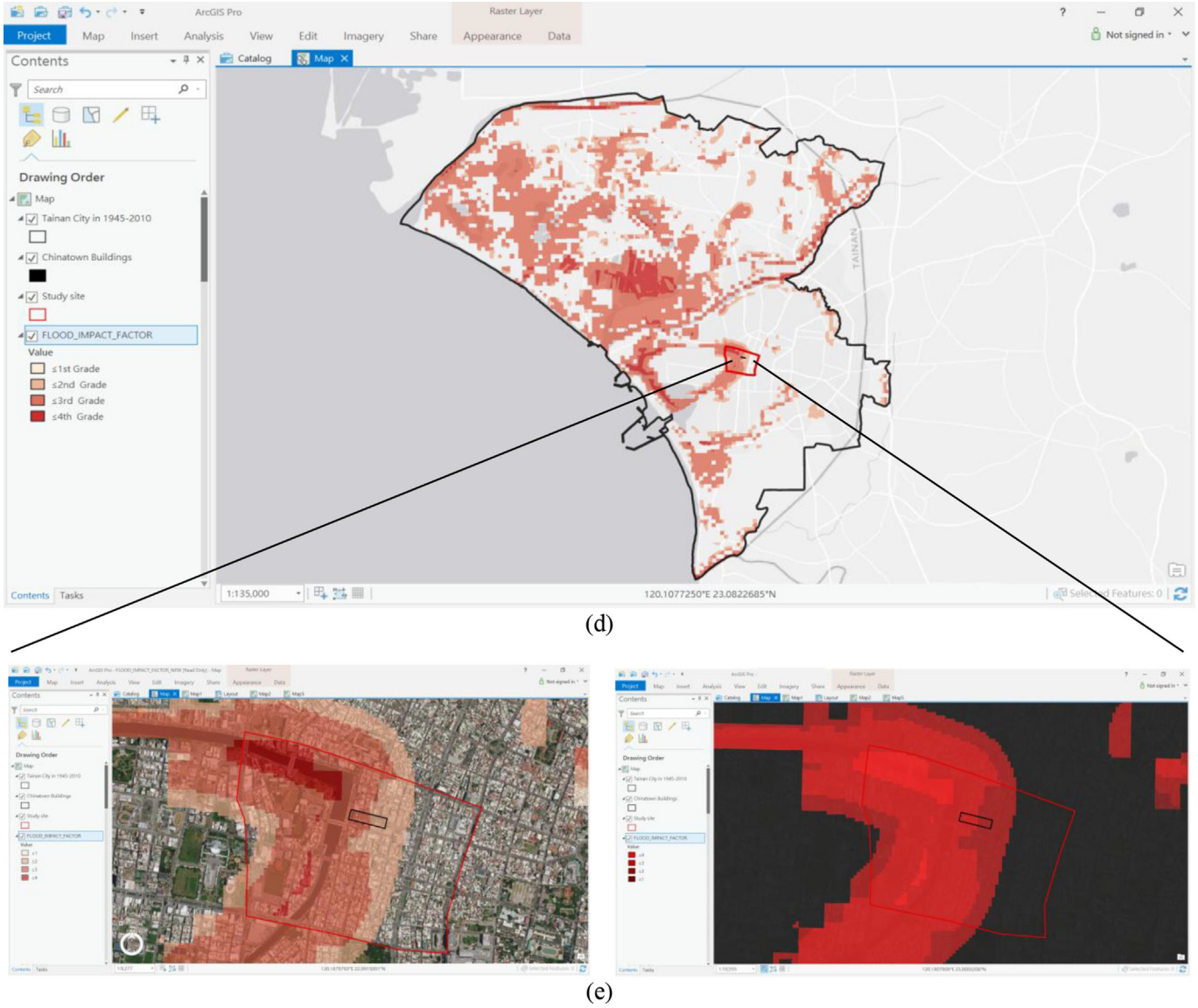


Fig. 5. (*continued*)

release of open geographic information, and the use of GISs have become relatively common. However, they have not yet employed geodesign as their design evaluation and analysis method. As the climate becomes increasingly extreme, landscape and urban planning-related designs must adopt geodesign to aid design analyses, assessments, and decisions (Eikelboom & Janssen, 2015; Flaxman, 2010; Steinitz, 2012) and ultimately enhance cities' ability to cope with natural disasters.

3. Results and discussions

3.1. Data analysis

Data analysis (phase 2) that covers data collection, information complication, and parameters formulation (steps 1–3) in this study involves simulating and visualizing the urban geographical environment, and its goal is to display and describe the related background information on the areas to be assessed. GIS has been widely used to visualize the current state of and future plans for urban environments. In addition, GIS can be used to display and simulate multiscale spatial data (Acutis et al., 2014; Oswald Beiler, Marroquin, & McNeil, 2016); this process primarily involves using the GIS map overlay function to integrate basic maps showing a city's current state (Fig. 4). Taiwan possesses almost complete basic maps, mostly consisting of open data and commercial electronic maps released by the government. ArcGIS Pro can be used to overlay buildings, road maps, green belts, river bodies, and terrains in the areas to be assessed, displaying their surrounding environmental information (on the GIS platform). In addition to presenting basic maps, this study entered related GIS maps into a geodatabase to serve as the basic information for subsequent 3D procedural modeling. The various map overlay results are presented as follows.

The study site is prone to the elevated sea levels and extreme rainfall. By using the ArcGIS software to plot a map of potential flood areas, the digital elevation model (DEM), and the distance grading map of the adjacent canal, the extent to which the West Central district is likely to be affected by extreme rainfall and the regions susceptible to flooding can be determined. This study selected the DEM with a resolution of 20 m, areas with a daily cumulative rainfall of 450 mm or more, and distance to the nearby canal as parameters to calculate the impact of flooding. The aforementioned maps were converted to 30 m grid data and graded as “very high,” “high,” “moderate,” or “low” risk. The definitions and grades of the factors affecting flooding (Kaźmierczak & Cavan, 2011; Kourgialas & Karatzas, 2016) are presented in Table 2. The original grid squares on the map of near river

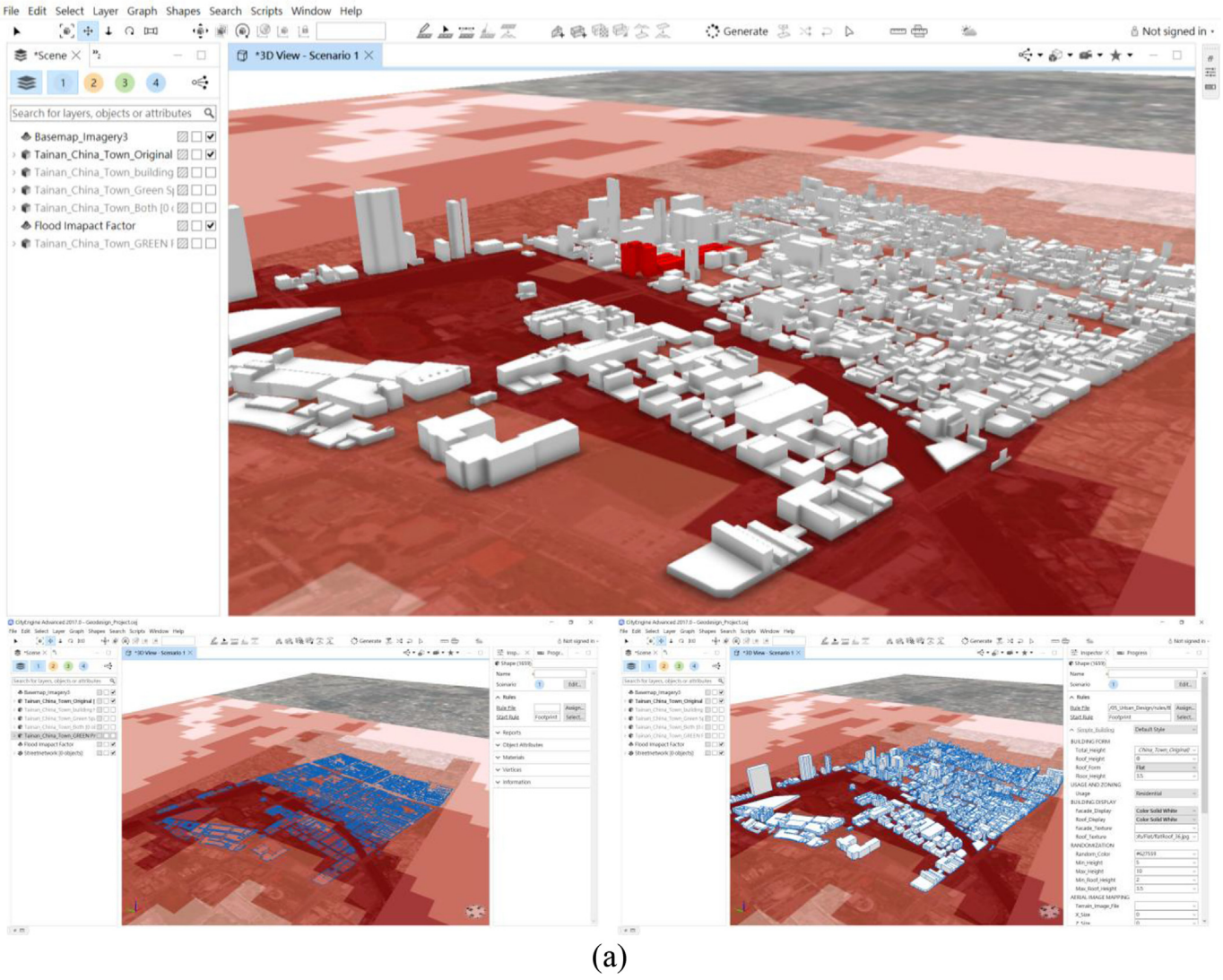


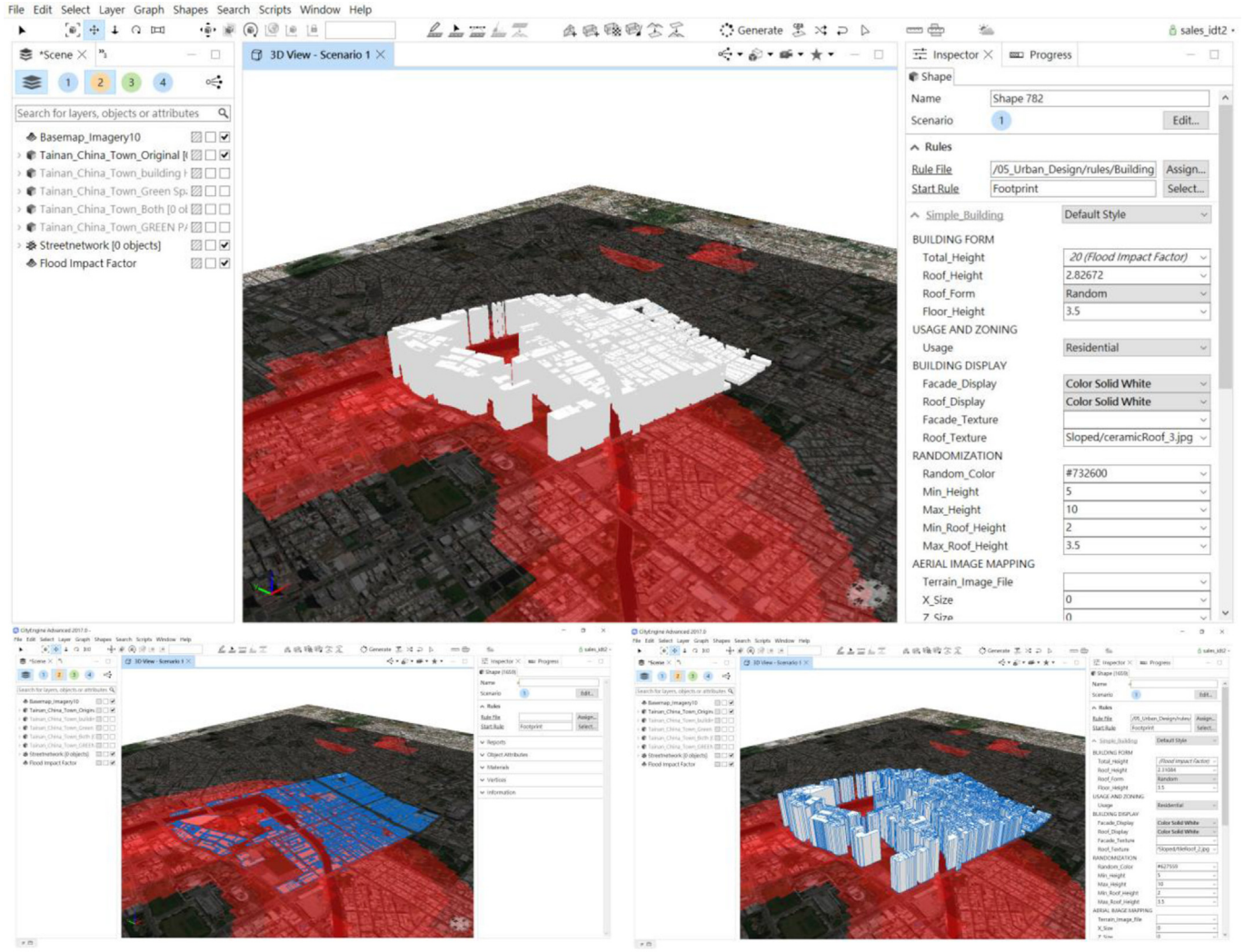
Fig. 6. CityEngine was used to demonstrate: (a) the study site in the flood potential map through GIS-based data analysis; (b) the building heights controlled by the flood potential map using rule-based design approach; (c) the green open space consisted of increasing permeable road surfaces and detention basins as web-based decision support. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

distance, elevation, and flood risk were reclassified into four grades using the ArcGIS reclassify tool, in which the total score for a grid square (calculated by adding up the grades) was obtained for the three factors (i.e., near river distance, elevation, and flood risk). Next, the effects (measured using percentages) were assigned weights by using the ArcGIS weighted overlay table tool before the grid data were added to produce the influential factors of flooding. The impact analysis in particular addressed calculation of influential factors of flooding as follows (Fig. 5):

- Calculate the grade indicating the distance to the adjacent canal by using the ArcGIS Euclidean distance tool;
- Obtain the 2 m resolution DEM grid data openly provided by the government (NDC, 2017), which indicates that the study area has flat, lowland terrain with the coast and a canal in its vicinity;
- Overlay satellite images and flooding potential diagrams of regions with daily cumulative rainfall of 450 mm, measured by the National Science and Technology Center for Disaster Reduction (NCDR)—the table identifies the areas susceptible to flooding and the extent of flooding in these areas (NCDR, 2018);
- Divide the grid data compiled in (a), (b), and (c) into four grades according to Table 2 and assign weights to the grid data using the ArcGIS weighted overlay tool, thereby deriving the influential factors of flooding – the flood potential map of the study.

3.2. Design optimization

Design optimization (phase 2) that includes design thinking, designing participation, and design evaluation (steps 4–6) in this study was focused on rule-based modeling that highlights a recent advancement of GIS technology and the 3D presentation method contributing to interactive communications among the public, decision-makers, and related stakeholders. This approach helps to understand more clearly the environmental state of and challenges encountered in the areas to be assessed during a geodesign evaluation process. In addition, 3D scenes enable the aforementioned parties to more quickly understand the problems on particular scales (Luo, He, & He, 2017; Smelik, Tutenel, de Kraker, & Bidarra, 2011; Yong, Mingmin, Yunliang, & Haiying, 2012). Esri CityEngine was used as the primary tool for building city model that enables easy integration of GIS information of the study areas, and adopts image overlay to present the regional environments (e.g., map of buildings, road networks, and water systems). That is, the tool writes related class, numerical, and material parameters to rules files, allowing the 3D scene of the study areas to be



(b)

Fig. 6. (*continued*)

promptly simulated using the procedural modeling method once the parameters have been determined (Grêt-Regamey, Celio, Klein, & Wissen Hayek, 2013).

This rule-based modeling of geodesign helps to interview experts and decision-makers from urban planning-based government departments who indicated that at present, the government will consider climate change adaptation measures when implementing long-term urban planning projects. On the basis of the adaptation strategies employed by the Tainan City Government and interviews conducted with urban planning experts, the influential factors of flooding were assigned to Grades 1–4 and their corresponding adaptation measures were compiled (Table 2). The adaptation measures presented, as aforementioned, increasing the capacities of flood detention facilities, using permeable road surfaces, and increasing green belt, garden, and park spaces were used as the design parameters for the rule-based models. The parameters were adjusted in the CityEngine according to the grades of the influential factors of flooding. This enabled the prompt simulation of 3D city models; the completed 3D model could be released as a CityEngine Web Viewer interface, serving as a platform on which the stakeholders, this is the public, experts, and decision-makers can participate in design-related discussions and collaborations. The CityEngine rule-based modeling methods was used and shared among the stakeholders to explore potential flood resilient measures as follows (Fig. 6):

- The study site in the flood potential map through *GIS-based data analysis*;
- The building heights controlled by the flood potential map (red channel) using *rule-based design optimization*;
- The green open space consisted of increasing permeable road surfaces and detention basins which increase the capacities of detention basins as *web-based decision support*, such as green belt, garden, and park spaces during flooding periods, and add more green belt areas to new building projects and dictate green belt ratios corresponding to the sizes of the building sites.

3.3. Decision support

Decision support (phase 3) that covers platform establishment, decision suggestion, and policy formulation (steps 7–9) in this study was conducted throughout Taiwan's first geodesign workshop, held on November 15th, 2016 at the School of Continuing Education of Chinese Culture University (SCE) to share the study results and software technologies. SCE has long earned and continuously enhanced its reputation as the pioneer and largest lifelong learning institution in the nation. The workshop was to elucidate the geodesign procedure defined by this study (Table 1) and discuss the test results obtained through the proposed procedure; its aim was the promotion of the application and development of geodesign in academic research. Based on that various

(c)

Fig. 6. (*continued*)

Table 3
The workshop participants' opinions and recommendations.

Participant	Summarized opinions and recommendations
Companies	- Geodesign enables people to think beyond their personal interests by providing real-world location images and impact analysis to realize the effects of flooding on their environment. - This workshop was an excellent way to initiate the promotion of geodesign so that geodesign applications and tools can be employed in actual design courses in the future. - The courses inspire students regarding the subjects of interdisciplinary design. In addition, promotion of 3D virtual reality and rule-based modeling should be continued in the future.
Students	- Public participation is extremely crucial. The use of 3D, simulation, and impact images enables the public to visualize the results, which makes communication with them considerably easier. - The Spatial Planning Act, Landscape Act, and Coastal Zone Management Act share the common goals of developing humanities and the environment based on sustainable usage. - This workshop clearly emphasized the aforementioned goals, and new and intuitive interfaces were employed to help people understand the problems and their solutions.
Professors	- Public participation geographic information systems had already been mentioned in previous GIS science–related discussions, in which the focus was on examining public participation. - Geodesign increases public participation by offering instant interactions and realistic technology, making future interdisciplinary collaborations more frequent and closely tied. - This event was particularly meaningful because it built a foundation on which the different school domains can work together. - On this platform, people can offer ideas, cooperate with one another, and work together to meet their common goals. - Previous urban development policies had been enacted on the basis of laws and regulations, making decision-making particularly difficult. - By contrast, geodesign evaluates impact levels and converts words into quantifiable data such as numbers and parameters, improving decision-making results.

feedback from companies, students, and professors in the fields of geography, urban design, and architecture were collected and are herein recorded (Table 3). It is also of concern that the expectation of the public is that the government can build *with* the people, not *for* the people.

The workshop was sharing with the participants the results of the study (Fig. 7) and explaining the nine-step geodesign framework procedure that involves data analysis, design optimization, and decision

Fig. 7. The workshop was sharing with the participants the results of the study.

support to determine current and future urban development. Decision-makers need to consider different possibilities during the decision-making process if they are to make accurate predictions; in addition, they shall use available data to predict likely events now and in the future and use that knowledge as the basis of their designs. Examining the demographics of the workshop participants showed that only few solely focused on the GIS field; this indicates that the traditional GIS field is no longer able to meet current demand. Nowadays, problem identification is no longer the only concern; problem solving has also become imperative. The use of GIS data integration and analyses as design supplementation to facilitate alleviating human and environmental problems will be a main trend in the future.

3.4. Climate adaptation

Cities are threatened by increasing flood risk under climate change. The design concept on the urban lagoon transformation introduced by the International Landscape Design Competition for Tainan Axis Transformation devised a successful project plan on flood risk management and urban resilience under climate change. However, restrictions imposed by the Tainan City Government prevented the two companies from demolishing the underground floors of China-Town Mall, resulting in these underground floors being the only flaw of the project. We argue that climate change is the most significant challenge to achieving sustainable urban development. As living conditions change, fast adaptation to these changes is necessary (Leong, 2016). Such adaptation may entail reinforcing or reconstructing existing buildings, engaging in migrations and/or relocations, and identifying solutions from the perspectives of humanity, the environment, and the economy (Meerow, Newell, & Stults, 2016). Climate adaptation entails more than just understanding climate change; it also involves comprehending the effect of climate change on local environments and the problems that must be solved. Geodesign employs GIS and spatial mapping technologies to simulate environmental background information and the effects that are currently being faced. Such information enables understanding the impact of climate change on the environment as well as the resulting problems. In addition, geodesign can be effectively integrated with urban planning and designs to generate specific adaptation plans to climate change (Brouns et al., 2015; Kourgialas & Karatzas, 2016).

The study results demonstrated that the study area will be highly susceptible to flooding during periods of extreme rainfall. The initial plan was to shut down the second underground floor and build shopping and dining streets on the first underground floor. However, this area would be prone to flooding. Furthermore, this project was primarily organized by the government and design experts, and the public's opinions were not sufficiently incorporated into the project designs and government's decisions. In a typical geodesign procedure, the opinions of and collaborations between the public, designers, decision makers, and related stakeholders are necessary during project planning and design (Aye et al., 2016; Neuenschwander et al., 2014). The local residents are in fact the individuals who are most familiar with the surrounding environment and the problems that need to be addressed. Thus, gathering the public's opinions and using them as a basis for urban planning and design is essential to designing spaces that the public truly needs (Brown & Kyttä, 2014; Haklay & Tobón, 2003).

4. Conclusion

Increasing flood risk in urban areas may be caused by extreme rainfall and sea level rise under climate change, and challenges sustainable urban development. As urban flood resilience is concerned, this study addressed the urban lagoon transformation of Tainan City introduced by the International Landscape Design Competition for Tainan Axis Transformation. We explored the gap towards flood resilient geodesign based on nine-step framework through data analysis (GIS-based), design optimization (rule-based), and decision support (web-based) process that helps to determine whether the lagoon design fully incorporated the influential factors of flooding in its urban planning. That is, geodesign approach enables people to understand and deal with the complex data analysis, design optimization, and decision support in adapting to climate impacts. In addition, rule-based modeling procedure of geodesign was used to incorporate flood risk factors to simulate the extent of flooding in the city. It provides a platform for interdisciplinary collaboration on which solutions to key future design problems can be identified. Social science, environmental science, agriculture, meteorology, and design can be integrated on the platform, and environmental changes can be examined and analyzed. It is noted that urban design and planning can be devised more accurately to optimize related solutions. We also indicated that the usage of geodesign based on GIS allowed participants mainly comprise local GIS software agents and dealers to reveal the user demographics of various GIS programs while GIS as a mature technology in Taiwan has been in development for more than two decades. It is noted that geodesign is a recently emerged theory in the fields of landscape, architecture, and urban planning and design, and has also become an international topic of scientific research on climate adaptation and resilience. However, geodesign is still in its infancy stage, and the number of research and academic units that have explored it remains few. Additionally, it is rarely used in practice by those in the urban design field. Lessons from the urban lagoon transformation of Tainan City indicate the need for flood resilience thinking and urban redevelopment that would facilitate government–public cooperation, enable the inclusion of both government and public opinion in urban design planning, and utilize the platform for design, communication, and interaction.

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